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(54) Title: COMPOUND CHIRP AND SYNCHRONIZER FOR USING SAME

(57) Abstract: A receiver receives a signal containing a compound chirp having a frequency up component and a frequency down component. The frequency up and down components overlap in time. A first correlator correlates the received signal with the frequency up component to produce a first correlation. A second correlator is arranged to correlate the received signal with the frequency down component to produce a second correlation. A processor determines a data block alignment offset by adding indices resulting from the first and second correlations, and the processor determines a carrier frequency offset by subtracting the indices resulting from the first and second correlations. The receiver is synchronized in accordance with the data block alignment offset and the carrier frequency offset.

COMPOUND CHIRP AND SYNCHRONIZER FOR USING SAME

Technical Field of the Invention

The present invention relates to a compound chirp and to a synchronizer for using the compound chirp to synchronize a receiver to a received signal.

Background of the Invention

Data communication systems typically involve a transmitter, a receiver, and a transmission path between the transmitter and receiver. The transmission path may be air or cables (wire or optical fiber). Data is frequently transmitted in a data communication system in a form which requires the receiver to be synchronized with the transmitter. For example, when data is spread in the frequency and/or time domains during transmission, the receiver must be synchronized to the transmitter in order to accurately recover the transmitted data.

A synchronizer typically uses a synchronization signal which is transmitted by the transmitter along with data. The synchronizer synchronizes the receiver to the synchronization signal and, when synchronization is acquired, the receiver is able to recover the data.

Copending U.S. Patent Application 09/108,433 filed on July 1, 1998 discloses an up chirp and a down chirp which may be transmitted as a synchronization

signal. A reference up chirp and a reference down chirp are correlated to the received signal in order to generate an up correlation peak index between the transmitted up chirp and the reference up chirp and a down correlation peak index between the transmitted down chirp and the reference down chirp. A frequency error is calculated based upon the difference between the up correlation peak index and the down correlation peak index, and a timing error is determined as the average of the up correlation peak index and the down correlation peak index. The frequency and timing errors are then used to acquire synchronization.

According to the arrangement disclosed in the aforementioned patent application, the up chirp and the down chirp are transmitted sequentially in time, as shown in Figure 1. Thus, the frequency of the up chirp increases from a frequency f_0 at a time t_0 to a frequency f_N at a time t_N, and the frequency of the down chirp decreases from the frequency f_N at the time t_N to the frequency f_0 at a time t_{2N}.

The present invention, on the other hand, is directed to a compound chirp which combines the attributes of both an up chirp component and a down chirp component but which, as shown in Figure 2, occupies a

shorter time interval than if the up chirp component and the down chirp component were transmitted sequentially. That is, as shown in Figure 2, the frequency of the compound chirp according to one embodiment of the present invention (i) increases from a frequency f_0 at a time t_0 to a frequency f_1 at a time t_M, (ii) decreases from a frequency f_2 at the time t_0 to a frequency f_1'' at the time t_M, (iii) increases from a frequency f_2'' at the time t_0 to a frequency f_3 at the time t_M, (iv) decreases from a frequency f_4 at the time t_0 to a frequency f_3'' at the time t_M, (v) increases from a frequency f_4'' at the time t_0 to a frequency f_5 at the time t_M, (vi) decreases from a frequency f_6 at the time t_0 to a frequency f_5'' at the time t_M, (vii) increases from a frequency f_6'' at the time t_0 to a frequency f_7 at the time t_M, and (viii) decreases from a frequency f_8 at the time t_0 to a frequency f_7'' at the time t_M. The time t_M may be shorter than, equal to, or longer than the time t_N. As shown in Figure 2, this compound chirp appears to be folded or pleated. The compound chirp of the present invention improves synchronization response times because it has a shorter duration than a non-folded chirp spanning the same bandwidth.

Summary of the Invention

According to one aspect of the present invention, a receiver receives a signal containing a compound chirp having frequency up and frequency down components. The frequency up and down components overlap in time. The receiver comprises first and second correlators and a processor. The first correlator correlates the received signal with the frequency up component to produce a first correlation. The second correlator correlates the received signal with the frequency down component to produce a second correlation. The processor determines synchronization parameters dependent upon the first and second correlations.

According to another aspect of the present invention, a compound chirp electrical signal comprises an up component and a down component. The up component varies in frequency from f_0 to f_1, and the down component varies in frequency from about f_1 to f_2, wherein $f_0 < f_1 < f_2$. The up and down components overlap in time so that f_0 of the up component occurs near in time to f_2 of the down component.

According to yet another aspect of the present invention, a method comprises: a) receiving a signal containing a transmitted compound chirp having N samples,

wherein the chirp is constructed so that the chirp effectively spans mN samples, wherein m and N are integers, and wherein m and N are unequal to one; b) correlating the received signal with a reference chirp; and, c) synchronizing a receiver in response to the correlation.

According to a further aspect of the present invention, a method of receiving a received signal containing a compound chirp having frequency up and frequency down components is provided. The frequency up and down components overlap in time. The method comprises: a) correlating the received signal with the frequency up component to produce a first correlation; b) correlating the received signal with the frequency down component to produce a second correlation; and, c) synchronizing a receiver based upon the first and second correlations.

According to yet a further aspect of the present invention, a compound chirp electrical signal comprises K frequency folds. Each frequency fold includes an up component and a down component, K ≥ one, and all of the K frequency folds overlap in time.

Brief Description of the Drawings

These and other features and advantages of the present invention will become more apparent from a detailed consideration of the invention when taken in conjunction with the drawings in which:

Figure 1 is a graph of a non-folded chirp having an up chirp component followed by a down chirp component in accordance with the aforementioned U.S. Patent Application 09/108,433;

Figure 2 is a graph showing an exemplary compound chirp according to the present invention;

Figure 3 is a schematic diagram of a transmitter and a receiver which provide an exemplary environment for the present invention;

Figure 4 shows an exemplary transmitter which may be used for the transmitter of Figure 3;

Figure 5 shows an exemplary receiver which may be used for the receiver of Figure 3, wherein the receiver includes a synchronizer in accordance with the present invention;

Figure 6 shows the real part of a 4096 point up chirp signal which may be used to generate a compound chirp according to a first embodiment of the present invention;

Figure 7 shows the imaginary part of the 4096 point up chirp signal which may be used to generate the compound chirp according to the first embodiment of the present invention;

Figure 8 shows the spectrum of the 4096 point up chirp signal shown in Figures 6 and 7;

Figure 9 shows the real part of an up component derived from the chirp signal shown in Figures 6, 7, and 8, where this up component may be used as a reference up chirp in connection with a synchronizer;

Figure 10 shows the imaginary part of the up component whose real part is shown in Figure 9;

Figure 11 shows the spectrum of this up component;

Figure 12 shows the real part of a down component derived from the chirp signal shown in Figures 6, 7, and 8, where this down component may be used as a reference down chirp in connection with a synchronizer;

Figure 13 shows the imaginary part of the down component whose real part is shown in Figure 13;

Figure 14 shows the spectrum of this down component;

Figure 15 shows the real part of a compound chirp which is derived from up chirp signal shown in Figures 6, 7, and 8;

Figure 16 shows the imaginary part of the compound chirp which is derived from up chirp signal shown in Figures 6, 7, and 8;

Figure 17 shows the spectrum of the compound chirp shown in Figures 15 and 16;

Figure 18 shows an exemplary data structure which includes the compound chirp and data according to the first embodiment of the present invention;

Figures 19 and 20 show properties of a compound chirp according to a second embodiment of the present invention;

Figure 21 shows an exemplary data structure which includes the compound chirp and data according to the second embodiment of the present invention;

Figure 22 shows the synchronizer of Figure 5 arranged for coarse synchronization;

Figure 23 shows an example of a correlation C(T) performed by the correlators of Figure 22; and,

Figure 24 shows the synchronizer of Figure 5 arranged for fine synchronization.

Detailed Description

As shown in Figure 3, a communication system 10 implementing synchronization according to the present invention generally includes a transmitter 12 and a receiver 14. The transmitter 12 transmits a signal containing data and a compound chirp over a communication path 16 to the receiver 14. For example, the communication path 16 can be air, space, cables, or any other medium supporting communication between the transmitter 12 and the receiver 14. To this extent, the transmitter 12 has a signal propagation device 18 such as a modem, an antenna, a satellite dish, or other equipment in order to propagate the signal through the communication path 16 to the receiver 14. Similarly, the receiver 14 has a signal acquisition device 20 which acquires the transmitted signal from the communication path 16 and provides the acquired signal to the receiver 14.

As shown in Figure 4, the transmitter 12 generally includes a data source 30, a coder 32 which codes the data supplied by the data source 30, an IFFT (inverse Fast Fourier Transform) 34 which performs a spectral transformation on the output of the coder 32, an adder 36 which adds the compound chirp of the present

invention to the output of the IFFT 34, a modulator 38 which modulates the output of the adder 36 onto a carrier, and a filter 39, such as a raised cosine filter, which filters the modulated carrier for supply to the signal propagation device 18. The coder 32 may implement any desired coding technique.

As shown in Figure 5, the receiver 14, in accordance with the present invention, includes a demodulator 40 which receives the signal acquired by the signal acquisition device 20 from the communication path 16, which demodulates the acquired signal down to baseband, and which supplies the demodulated signal to an analog to digital (A/D) convertor 42. The A/D convertor 42 samples the demodulated signal at a predetermined sampling frequency, which is alternatively referred to herein as the Nyquist frequency. (On the other hand, the demodulator 40 and the A/D convertor 42 may be arranged to demodulate the acquired signal down to IF, to sample the acquired signal at IF, and to demodulate the samples down to baseband.) The samples from the demodulator 40 and the A/D convertor 42 are filtered by a filter 44, such as a raised cosine filter.

The filtered samples are supplied to a block alignment 46, which operates in response to a block

offset signal as discussed below, and which adjusts the actual temporal location of data blocks as received relative to the temporal location of the received data blocks as assumed by the receiver 14. The output of the block alignment 46 is spectrally transformed by an FFT (Fast Fourier Transform) 48. The output of the FFT 48 is provided to a synchronizer 50 which synchronizes the receiver 14 by supplying a carrier frequency offset signal to the demodulator 40, a signal to control the sampling frequency of the A/D convertor 42, and a data block alignment signal to control the block alignment 46. The output of the FFT 48 is also provided to an equalizer 52 which reduces intersymbol or interdata interference in the received data blocks. Finally, a decoder 54 decodes the equalized signal in order to recover the data which was originally supplied by the data source 30.

In order for the synchronizer 50 to synchronize the receiver 14 to the signal received from the transmitter 12, the transmitter 12 provides a compound chirp along with the data propagated by the signal propagation device 18 over the communication path 16 to the signal acquisition device 20. Two embodiments of a compound chirp, one for VSB systems and one for QAM

systems, are described herein, although compound chirps for other types of systems can be provided as well.

VSB COMPOUND CHIRP

A linear frequency modulation signal, having 4096 samples and a frequency increasing from a low value such as zero to a high value such as the Nyquist frequency, is created based upon a sampling frequency fs. For example, fs = 10.76 MHZ. The linear frequency modulation signal may be provided in accordance with $\sin(\omega t^2)$. The real part of the 4,096 samples is shown in Figure 6, the imaginary part of the 4,096 samples is shown in Figure 7, and the spectrum of the 4,096 samples is shown in Figure 8. (Alternatively, the 4,096 samples could be derived from a signal having a decreasing frequency.)

The 4,096 samples are partitioned evenly into eight segments each having 512 samples, where the first segment contains the first 512 samples, the second segment contains the next 512 samples, . . ., and the eighth segment contains the last 512 samples. The complex conjugate is taken of the even numbered segments (i.e., the second, fourth, sixth, and eighth segments) in order to produce a 90^0 phase shift, and the complex

conjugated even numbered segments are each reversed by index. During index reversal, the first sample and the last sample of the complex conjugated second segment are switched, the second sample and the next to last sample of the complex conjugated second segment are switched, and so on. Also, the first sample and the last sample of the complex conjugated fourth segment are switched, the second sample and the next to last sample of the complex conjugated fourth segment are switched, and so on. The sixth and eighth complex conjugated segments are similarly processed.

The first, third, fifth, and seventh segments are linearly added to produce a 512 sample up component of the compound chirp. Thus, the first samples of the first, third, fifth, and seventh segments are added to produce a first sample in the 512 sample up component, the second samples of the first, third, fifth, and seventh segments are added to produce a second sample in the 512 sample up component, and so on. The 512 sample up component is suitably transformed (such as by an FFT) to produce a spectrum that is used as a reference up component by the synchronizer 50 to acquire synchronization as described below. Figure 9 shows the real part of the 512 sample reference up component,

Figure 10 shows the imaginary part of the 512 sample reference up component, and Figure 11 shows the spectrum of the 512 sample reference up component.

Similarly, the complex conjugated and index reversed second, fourth, sixth, and eighth segments are linearly added to produce a 512 sample down component of a compound chirp. The 512 sample down component is suitably transformed (such as by an FFT) to produce a spectrum that is used as a reference down component by the synchronizer 50 to acquire synchronization as described below. Figure 12 shows the real part of the 512 sample reference down component, Figure 13 shows the imaginary part of the 512 sample reference down component, and Figure 14 shows the spectrum of the 512 sample reference down component.

The 512 sample reference up component and the 512 sample reference down component are linearly added to produce the 512 sample compound chirp shown in Figure 2 that is transmitted by the transmitter 12 and that permits the receiver 14 to acquire synchronization. The samples in the 512 sample compound chirp are suitably weighted so as to normalize power. Figure 15 shows the real part of the 512 point compound chirp, Figure 16

shows the imaginary part of the 512 point compound chirp, and Figure 17 shows the spectrum of the compound chirp.

The 90^0 phase shift introduced into the second, fourth, sixth, and eighth segments as a result of the complex conjugation is necessary so that, when the reference down component and the reference up component are combined to produce the compound chirp, the corners of the compound chirp (such as f_1, f_1'' of Figure 2) do not have precisely the same frequency.

Figure 18 shows an exemplary data and compound chirp structure transmitted by the transmitter 12 when operating in a VSB mode, although other structures could be used. According to the structure shown in Figure 18, data is transmitted in a series of data blocks. A compound chirp is transmitted before each data block and, as described in more detail below, permits the receiver 14 to synchronize to the received signal so that the receiver can properly recover the data in the data blocks.

QAM COMPOUND CHIRP

A linear frequency modulation signal, having 16,384 sample points and a frequency increasing from a low value such as zero to a high value such as the

Nyquist frequency is created based upon a sampling frequency fs_1. For example, fs_1 = 5.38 MHZ. The linear frequency modulation signal may be provided in accordance with $\sin(\omega t^2)$. (Alternatively, the 16,384 samples could be derived from a signal having a decreasing frequency.)

These 16,384 samples are Hilbert transformed and the upper half of the samples (i.e., the 8,192 samples from sample 8,193 to sample 16,384 in the time domain and from ½ fs to fs in the frequency domain) are complex conjugated in order to phase shift the samples by 90^0 and are reversed by index in order to form a down component from fs to ½ fs in the frequency domain. The lower half of the samples (i.e., the 8,192 samples from sample 1 to sample 8,192 in the time domain and from 0 to ½ fs in the frequency domain) forms an up component of a compound chirp.

Accordingly, an 8,192 sample up component and an 8,192 sample down component are formed. The 8,192 sample up component and the 8,192 sample down component are each down sampled. These chirps may be down sampled, for example, by discarding all even samples or all odd samples. The samples remaining after down sampling (i.e., the samples in the resulting 4,096 sample up component and in the resulting 4,096 sample down

component) are suitably weighted so as to normalize power. The resulting 4,096 sample up component may be spectrally transformed and then used as the reference up component by the receiver 14 when operating in a QAM mode. Similarly, the resulting 4,096 sample down component may be spectrally transformed and then used as a reference down component by the receiver 14 when operating in a QAM mode. The reference up component and the reference down component are linearly added to produce the 4,096 sample compound chirp for QAM mode receivers.

Figures 19 and 20 show the properties of the 4,096 sample QAM compound chirp. Figure 21 shows an exemplary data and chirp structure transmitted by the transmitter 12 when operating in a QAM mode, although other structures could be used. According to the structure shown in Figure 21, data is transmitted in a series of data blocks. A compound chirp is transmitted so as to overlap each data block in time. The compound chirp may be transmitted 12 db down, for example, from its corresponding data block and, as described in more detail below, permits the receiver 14, when operating in the QAM mode, to synchronize to the received signal so

that the receiver 14 can properly recover the data in the data blocks.

SYNCHRONIZER 50

Coarse adjustment of the synchronizer 50 is described herein with respect to Figure 22. As discussed above, the compound chirp (either VSB or QAM) is added to the transmitted data by the transmitter 12. In the communication path 16, the signal propagated by the signal propagation device 18 may encounter various signal impairments such as frequency and phase offset. In the receiver 14, it is necessary to lock the carrier and the sampling clock and to perform data block alignment. The compound chirp signal contains the necessary information for the synchronizer 50 to perform these locking and alignment functions.

The synchronizer 50 includes a pair of correlators 60 and 62. The correlator 60 includes a multiplier 64 which multiplies the output of the FFT 48 by a reference S1, an inverse spectral transformation 66 which performs an inverse spectral transformation on the output of the multiplier 64, and a processor 68 which, *inter alia*, performs a summation operation to complete the up correlation. The correlator 62 includes a

multiplier 70 which multiplies the output of the FFT 48 by a reference S2, an inverse spectral transformation 72 which performs an inverse spectral transformation on the output of the multiplier 70, and the processor 68 which, *inter alia*, performs a summation operation to complete the down correlation. The reference S1 is the reference up component of either the VSB type or the QAM type as described above, depending upon whether the receiver 14 is operating in the VSB mode or the QAM mode. Similarly, the reference S2 is the reference down component of either the VSB type or the QAM type as described above, depending upon whether the receiver 14 is operating in the VSB mode or the QAM mode. By correlating the received signal to the reference up and down components, any frequency displacement between the received compound chirp and the reference up and down components appears as time shifts between the compound chirp and the reference up and down components. That is, the correlation peak looks as if it is time shifted from the center correlation output.

The correlators 60 and 62 perform their correlations essentially according the following equation:

$$C(T) = \sum_{t=-L/2}^{L/2} x(t) \cdot y^{*}(t-T) \qquad (1)$$

where L is defined as the number of samples in a chirp and is representative of the length of a chirp (i.e., the transmitted compound chirp, the reference up component, or the reference down component, which all have the same length), where the quantity x(t) represents the received compound chirp, where the quantity y(t-T) represents the reference up component or the reference down component, as appropriate, and where * represents a complex conjugate function. The index T in equation (1) is varied from -N to N, where T is the index number of the samples in a chirp, and where there are a total of N samples in a chirp. Figure 23 shows an example of the correlations C(T) from -N to N. The correlation can be performed in any domain.

The index T in equation (1) should be varied by the correlator 60 over the whole up component, and the index T in equation (1) should be varied by the correlator 62 over the whole down component. Thus, each correlation is performed over all T. The center of the correlation is defined as the correlation point where T

is 0. The results of the correlations performed by the correlators 60 and 62 are processed by the processor 68 in order to determine a block offset and a carrier frequency offset.

More specifically, the processor 68 weights the indices of the up correlation peaks with their corresponding peak amplitudes and averages these weighted correlation peak indices in order to determine an index $T_{up\text{-}peak}$, and the processor 68 weights the indices of the down correlation peaks with their corresponding peak amplitudes and averages these weighted correlation peak indices in order to determine an index $T_{down\text{-}peak}$. The block offset (i.e., the difference between the temporal location of the received data blocks as assumed by the receiver 14 and the actual temporal location of the data blocks as received) is determined by the processor 68 by summing the index $T_{up\text{-}peak}$ and the index $T_{down\text{-}peak}$. The carrier frequency offset (i.e., the difference between the received carrier frequency and the carrier frequency assumed by the receiver 14) is determined by the processor 68 by subtracting the index $T_{up\text{-}peak}$ and the index $T_{down\text{-}peak}$.

The block offset and the carrier frequency offset may be used as shown in Figure 5 in order to

synchronize the receiver 14 to the received carrier frequency and blocks of data. Accordingly, the data blocks are aligned by shifting each data block by the block offset or by using the block offset to reset the start of each data block at the receiver 14. Similarly, the carrier frequency in the receiver 14 is set according to the carrier frequency offset. Both data block alignment and carrier frequency setting can be performed at the same time.

Fine adjustment of the synchronizer 50 is shown with respect to Figure 24. The synchronizer 50 includes single point correlators 80, 82, 84, and 86. That is, the single point correlators 80, 82, 84, and 86 perform a correlation according to equation (1) with T set to 0 during the correlation (i.e., T is not varied). The single point correlator 80 includes a multiplier 88 and a processor 90 which perform a single point up correlation. The multiplier 88 multiplies the output of the FFT 48 by the reference S1. The single point correlator 82 includes a multiplier 92 and the processor 90 which perform a single point down correlation. The multiplier 92 multiplies the output of the FFT 48 by the reference S2. The single point correlator 84 includes a multiplier 94 and the processor 90 which perform a single point

correlation. The multiplier 94 multiplies the output of the FFT 48 by a reference S3. The single point correlator 86 includes a multiplier 96 and the processor 90 which perform a single point correlation. The multiplier 96 multiplies the output of the FFT 48 by a reference S4.

The reference S1 is the reference up component described above, and is either of the VSB type or the QAM type depending upon whether the receiver 14 is operating in the VSB mode or the QAM mode. Similarly, the reference S2 is the reference down component described above, and is either of the VSB type or the QAM type depending upon whether the receiver 14 is operating in the VSB mode or the QAM mode.

The reference S3 is a reference compound chirp derived by shifting the compound chirp to the left by half of a sample, and the reference S4 is a reference compound chirp derived by shifting the compound chirp to the right by half of a sample.

The indices of the peaks resulting from the single point correlation 80 are weighted by the processor 90 with their corresponding peak amplitudes and are averaged by the processor 90 to determine the index $T_{up\text{-}peak}$, and the indices of the peaks resulting from the

single point correlation 82 are similarly weighted by the processor 90 with their corresponding peak amplitudes and are averaged by the processor 90 to determine the index $T_{down\text{-}peak}$. The block offset is determined by the processor 90 by summing the index $T_{up\text{-}peak}$ and the index $T_{down\text{-}peak}$. The carrier frequency offset is determined by the processor 90 by subtracting the index $T_{up\text{-}peak}$ and the index $T_{down\text{-}peak}$.

The outputs of the single point correlations 84 and 86 are processed by the processor 90 according to the following expression in order to produce sampling clock frequency and phase information:

$$\frac{|\Sigma(D \cdot R_{up})|}{|\Sigma(D \cdot R_{down})|} - 1 \qquad (2)$$

wherein D is the received signal with the compound chirp, wherein R_{up} is the reference S3, and wherein R_{down} is the reference S4. The sampling clock frequency and phase information may be used in a conventional manner in order to adjust the frequency and phase of the sampling clock so as to finely synchronize the receiver 14.

Certain modifications of the present invention have been discussed above. Other modifications will occur to those practicing in the art of the present

invention. For example, the invention is described above in terms of a vestigial sideband (VSB) system and a quadrature amplitude modulation (QAM) system. However, in a modified form, the present invention described above also may be used in single sideband (SSB) and double sideband (DSB) systems.

Also, the present invention has been described above in the context of transmissions from the transmitter 12 to the receiver 14. However, the transmitter 12 and the receiver 14 may be bi-directional transmitting and receiving devices.

Moreover, the spectral transformations as described above are performed using an FFT pair (i.e., the IFFT 34 and the FFT 48). However, other transformations could be used to perform the spectral transformation.

Furthermore, as described above, the compound chirp created for VSB systems has more frequency folds than does the compound chirp created for QAM systems. Alternatively, the compound chirp created for QAM systems could have more frequency folds than does the compound chirp created for VSB systems, or the compound chirp created for VSB systems and the compound chirp created for QAM systems could have the same number of frequency

folds. Also, the compound chirp created for VSB systems and the compound chirp created for QAM systems can have any number of folds.

Additionally, although the compound chirp and the reference up and down components are described above as being created in the same domain, the compound chirp and the reference up and down components could be created in any domain as long as the compound chirp and the reference up and down components are in the same domain at the time that they are correlated.

In addition, as described above, the indices of the correlation peaks are weighted and are averaged to determine the indices $T_{up\text{-}peak}$ and $T_{down\text{-}peak}$ as appropriate. Alternatively, the index of the biggest correlation peak from the up correlation and the index of the biggest correlation peak from the down correlation could be used as the indices $T_{up\text{-}peak}$ and $T_{down\text{-}peak}$, respectively. As a still further alternative, the centroid of the up correlation and the centroid of the down correlation could be used as the indices $T_{up\text{-}peak}$ and $T_{down\text{-}peak}$, respectively.

Also, as described above, a compound chirp includes both at least one up component and at least one

down component. Instead, a compound chirp could include only plural up components or only plural down components.

Accordingly, the description of the present invention is to be construed as illustrative only and is for the purpose of teaching those skilled in the art the best mode of carrying out the invention. The details may be varied substantially without departing from the spirit of the invention, and the exclusive use of all modifications which are within the scope of the appended claims is reserved.

WHAT IS CLAIMED IS:

1. A receiver (14), wherein the receiver (14) receives a received signal containing a chirp having first and second frequency components, the receiver (14) BEING CHARACTERIZED IN THAT:

the chirp is a compound chirp such that the first and second frequency components overlap in time; and,

the receiver (14) performs a synchronization dependent upon the compound chirp.

2. The receiver of claim 1 comprising:

a first correlator (60 or 80) arranged to correlate the received signal with the first frequency component to produce a first correlation;

a second correlator (62 or 82) arranged to correlate the received signal with the second frequency component to produce a second correlation; and,

a processor (68) arranged to determine synchronization parameters dependent upon the first and second correlations.

3. The receiver of claim 2 wherein the synchronization parameters include data block alignment offset.

4. The receiver of claim 3 wherein the processor (68) determines the data block alignment offset by summing indices resulting from the first and second correlations.

5. The receiver of claim 2, 3, or 4 wherein the synchronization parameters include carrier frequency offset.

6. The receiver of claim 5 wherein the processor (68) determines the carrier frequency offset by subtracting indices resulting from the first and second correlations.

7. The receiver of claim 2 wherein the first and second correlators (80 and 82) comprise multipliers (88 and 92), and wherein the receiver (14) further comprises third and fourth correlators (84 and 86), wherein the third and fourth correlators (84 and 86) comprise third and fourth multipliers (94 and 96),

respectively, wherein the third multiplier (94) is arranged to multiply the received signal with a first reference compound chirp (S3) to produce a third correlation, wherein the fourth multiplier (96) is arranged to multiply the received signal with a second reference compound chirp (S4) to produce a fourth correlation, wherein the first and second reference compound chirps (S3 and S4) are the compound chirp half sample shifted to the left and to the right respectively, and wherein the processor (68) is arranged to perform the synchronization dependent upon the third and fourth correlators (84 and 86).

8. The receiver of claim 2 wherein the first correlation is a weighted average of correlation peaks produced by the first correlator (60), and wherein the second correlation is a weighted average of correlation peaks produced by the second correlator (62).

9. The receiver of claim 1 wherein the first frequency component varies in frequency from f_0 to f_1, wherein the second frequency component varies in frequency from about f_1 to f_2, wherein $f_0 < f_1 < f_2$, and wherein the first and second frequency components overlap

in time so that f_0 occurs nearer in time to f_2 than does f_1.

10. The receiver of claim 9 wherein the second frequency component varies in frequency from f_1'' to f_2, wherein f_1 is near f_1'' in frequency, wherein $f_0 < f_1 < f_1'' < f_2$, and wherein the first and second frequency components overlap in time so that f_1 of the first frequency component occurs near in time to f_1'' of the second frequency component.

11. The receiver of claim 1 wherein the compound chirp spans a bandwidth of a channel through which the compound chirp is transmitted.

12. The receiver of claim 1 wherein the receiver (14) correlates the received signal with a reference compound chirp and synchronizes itself to the received signal in accordance with the correlation.

13. The receiver of claim 12 wherein the receiver (14) synchronizes itself to the received signal based upon a summation of indices resulting from the correlation.

14. The receiver of claim 12 or 13 wherein the receiver (14) synchronizes itself to the received signal based upon a subtraction of indices resulting from the correlation.

15. The receiver of claim 1 or 12 wherein the compound chirp comprises N samples derived by (i) producing mN samples representing a signal having an increasing or decreasing frequency, (ii) partitioning the mN samples into m segments each having N samples, wherein the m segments include m/2 even segments and m/2 odd segments, (iii) processing the m/2 even segments or the m/2 odd segments so that the processed segments represent a phase shifted chirp segment having a frequency changing in an opposite sense to the frequency of the signal, and (iv) combining the m/2 processed segments and the m/2 unprocessed segments so as to produce the N samples.

16. The receiver of claim 15 wherein m = 8 and N = 512.

17. The receiver of claim 15 wherein m = 8 and N = 4096.

18. The receiver of claim 15 wherein the processed and unprocessed segments are combined by linearly adding the m/2 processed segments and the m/2 unprocessed segments.

19. The receiver of claim 15 wherein the processed segments are produced by complex conjugating the m/2 even segments or the m/2 odd segments and by index reversing the complex conjugated even or odd segments.

20. The receiver of claim 19 wherein the processed and unprocessed segments are combined by linearly adding the m/2 processed segments and the m/2 unprocessed segments.

21. The receiver of claim 15 wherein m < N.

22. The receiver of claim 1 wherein the receiver (14) synchronizes itself to the received signal by correlating the received signal with first and second reference compound chirps, wherein the first and second reference compound chirps are the compound chirp half

sample shifted to the left and to the right, respectively.

23. The receiver of claim 1 wherein the compound chirp comprises at least one frequency up component and at least one frequency down component.

24. The receiver of claim 1 wherein the compound chirp comprises only frequency up components.

25. The receiver of claim 1 wherein the compound chirp comprises only frequency down components.

26. The receiver of claim 1 wherein the compound chirp signal comprises K frequency folds, wherein each frequency fold includes a frequency up component and a frequency down component, wherein $K \geq$ two, and wherein all of the K frequency folds overlap in time.

27. The receiver of claim 1 wherein the compound chirp comprises at least first, second, and third frequency components, and wherein the first,

second, and third frequency components overlap in time with each other.

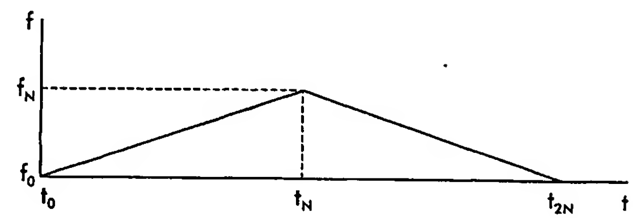


Figure 1

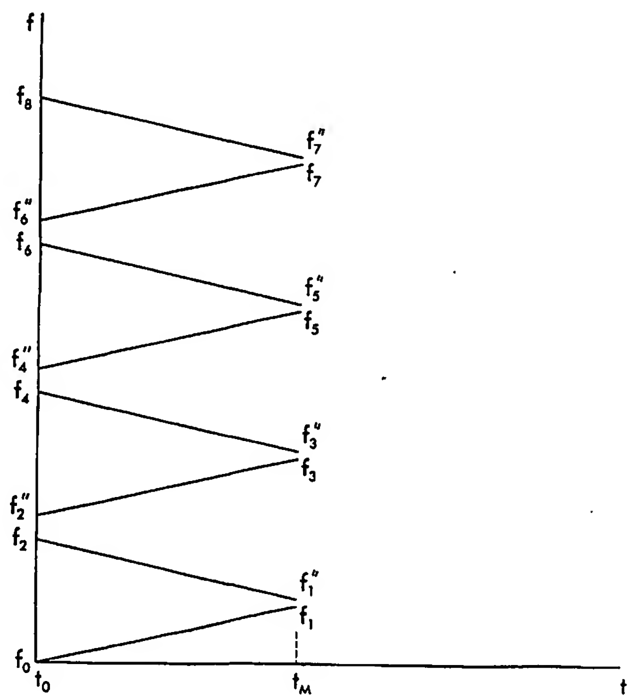
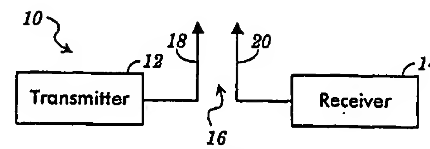


Figure 2



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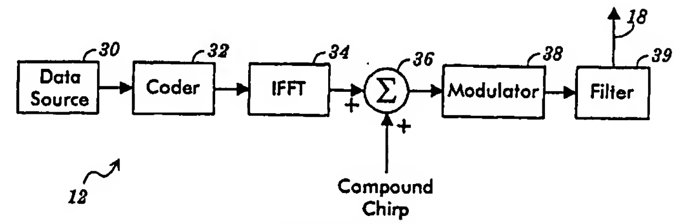

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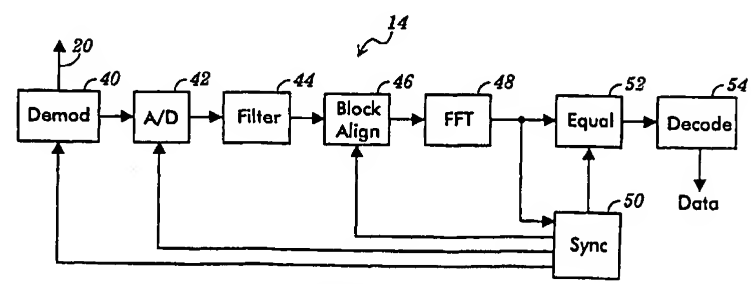

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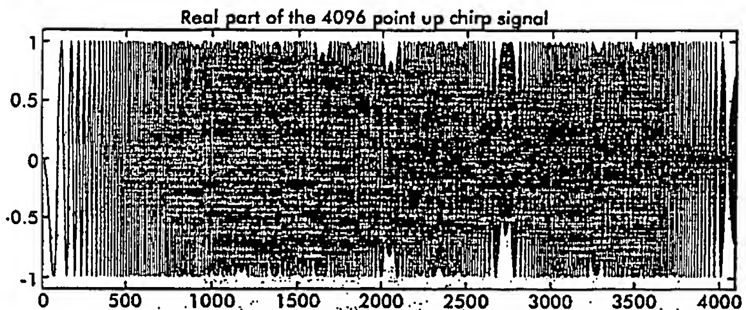

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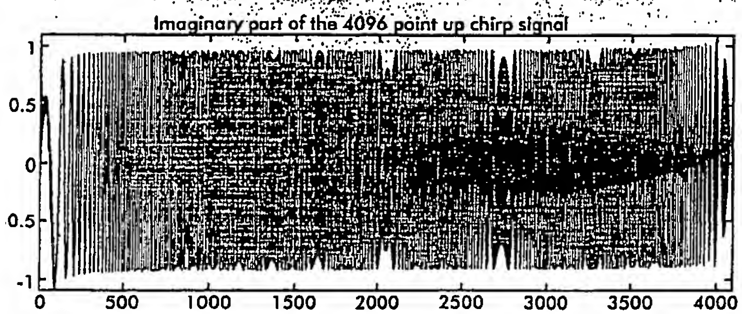

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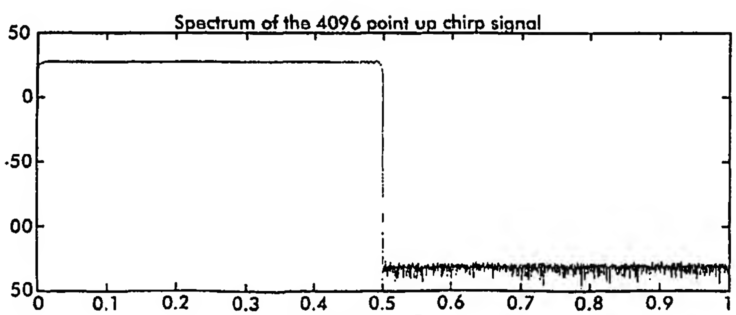

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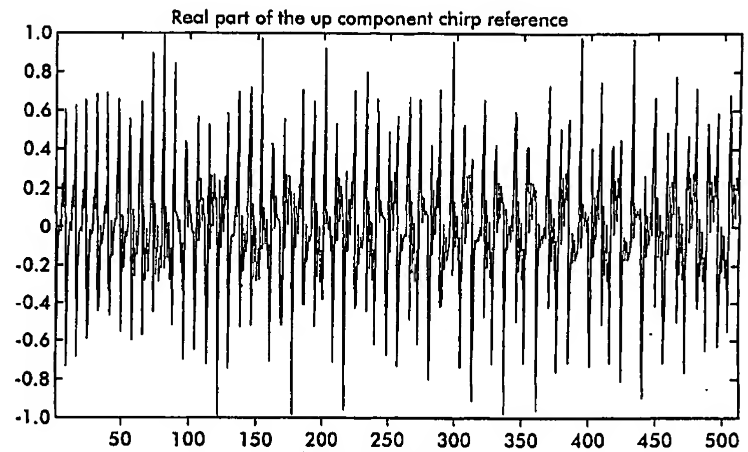

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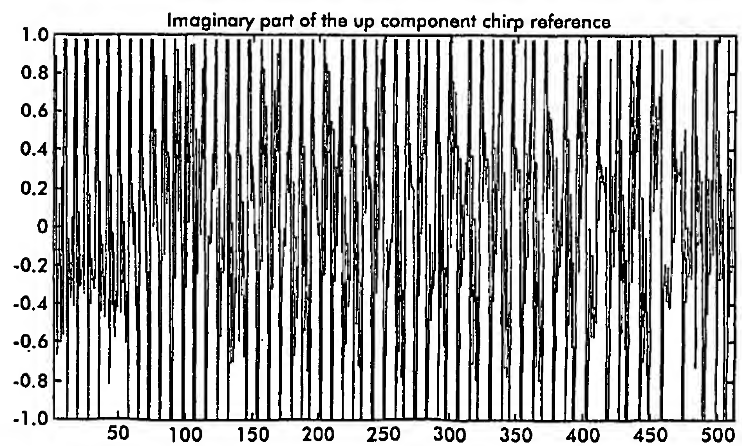
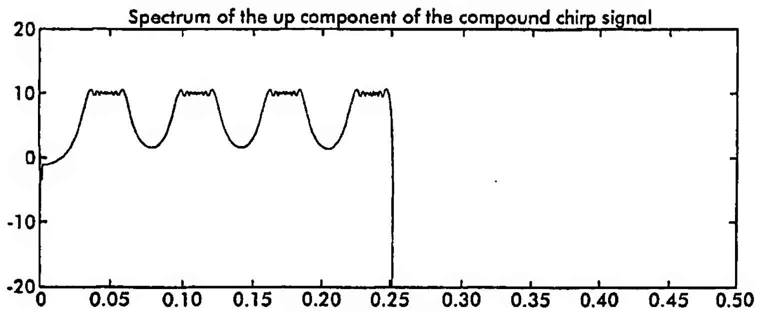


Figure 10



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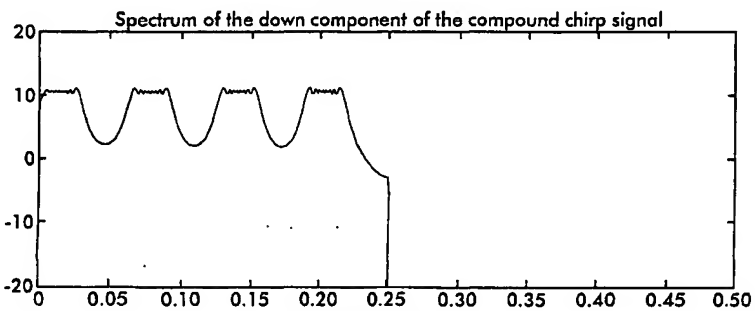

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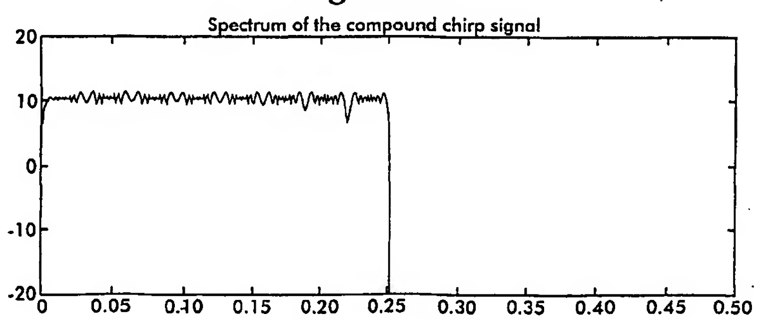

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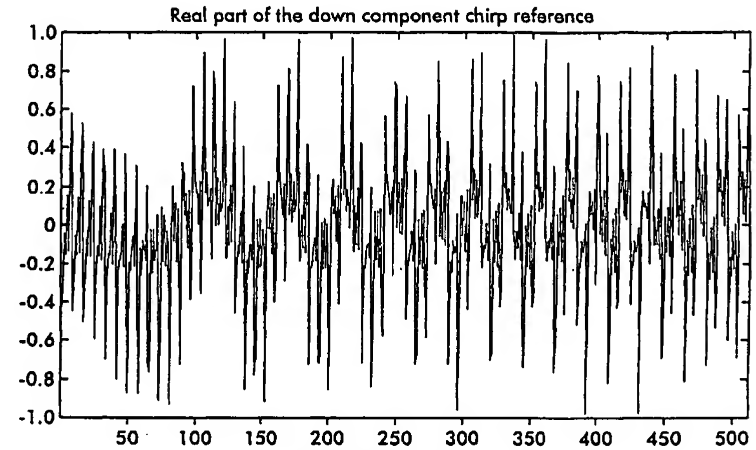

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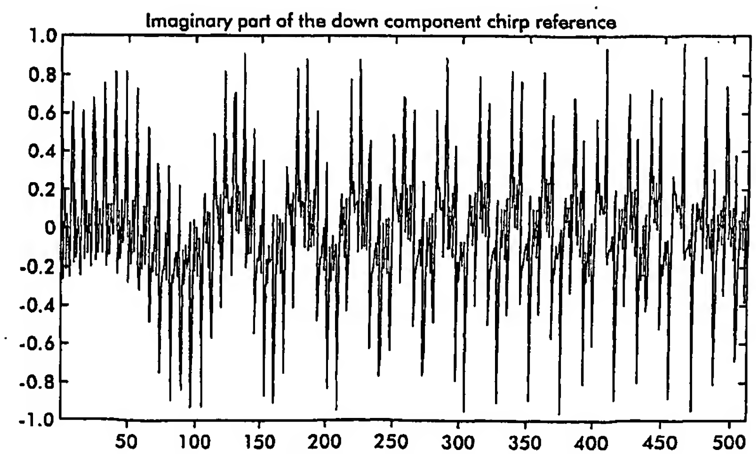
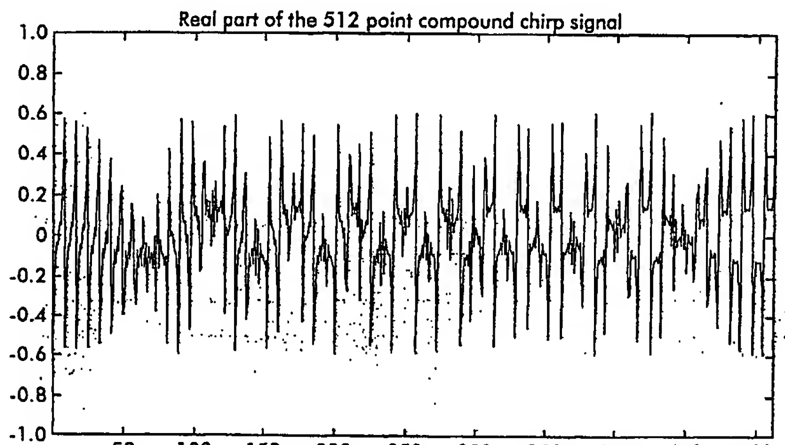


Figure 13



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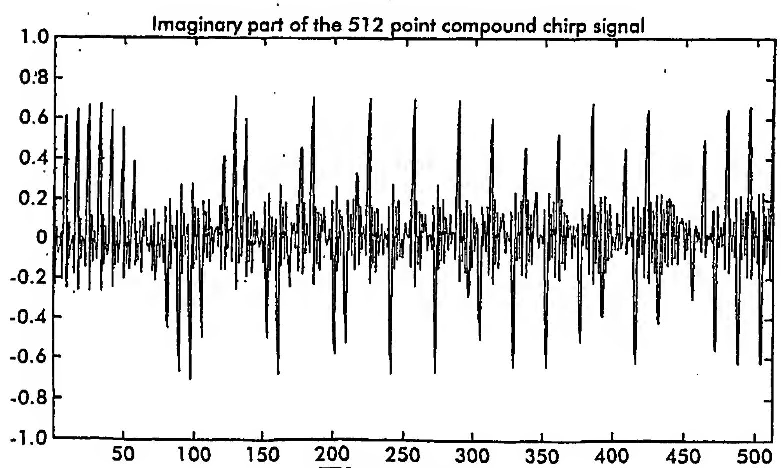

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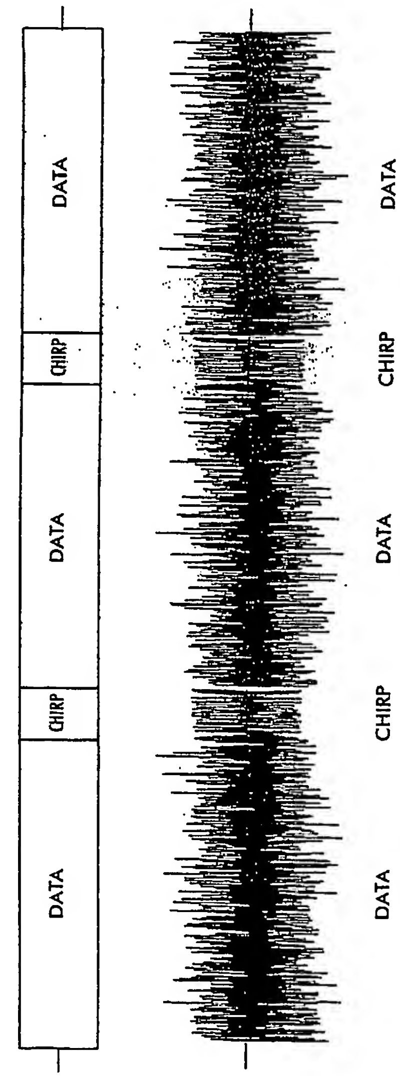

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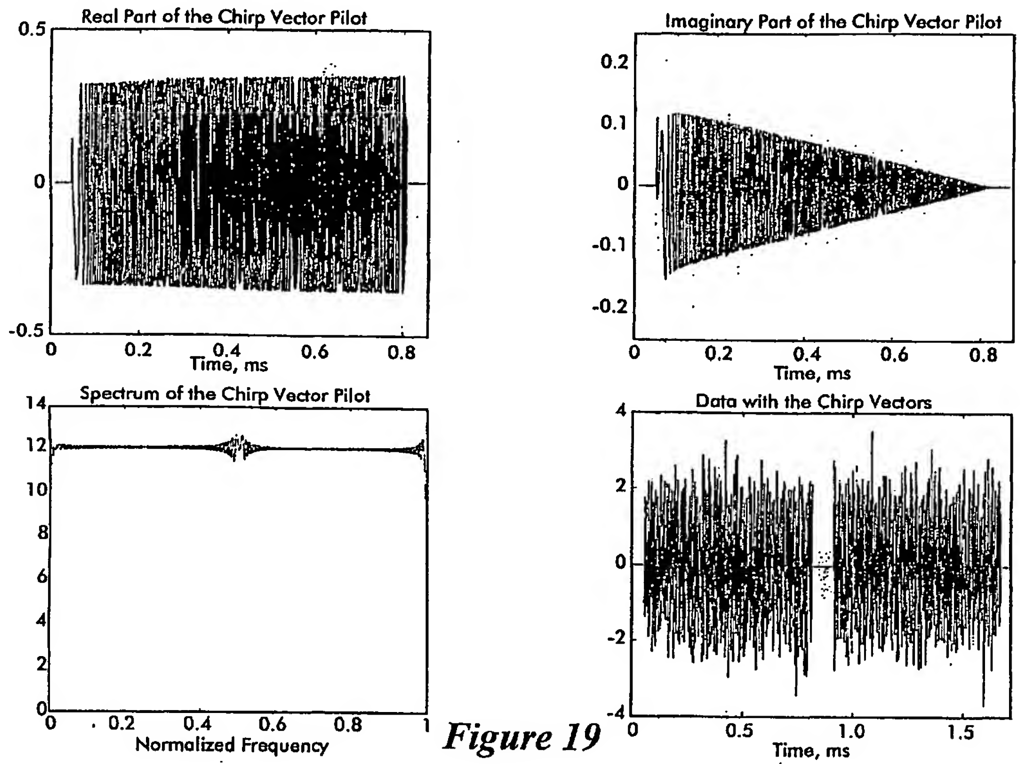

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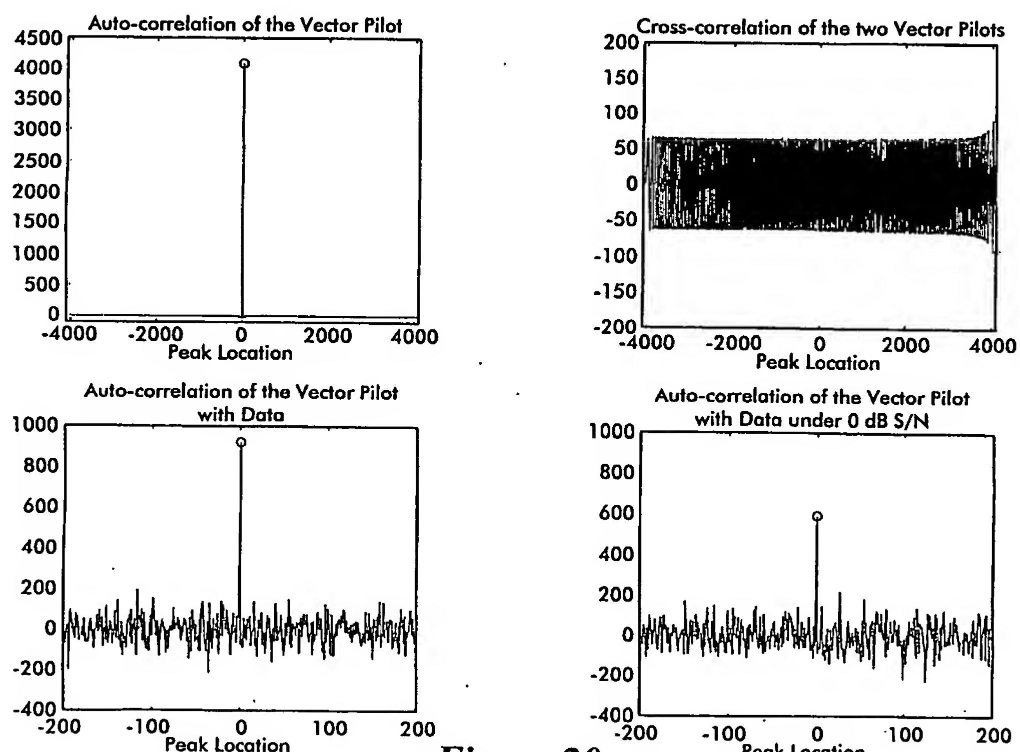

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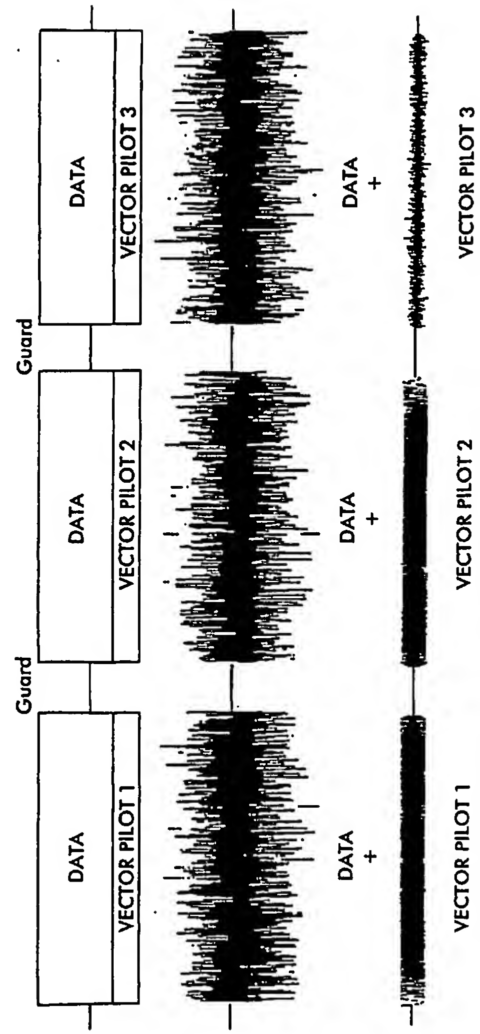

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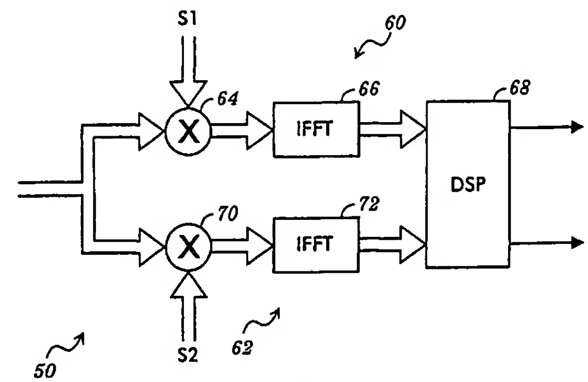

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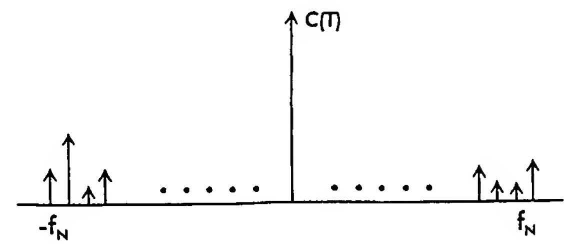

Figure 23

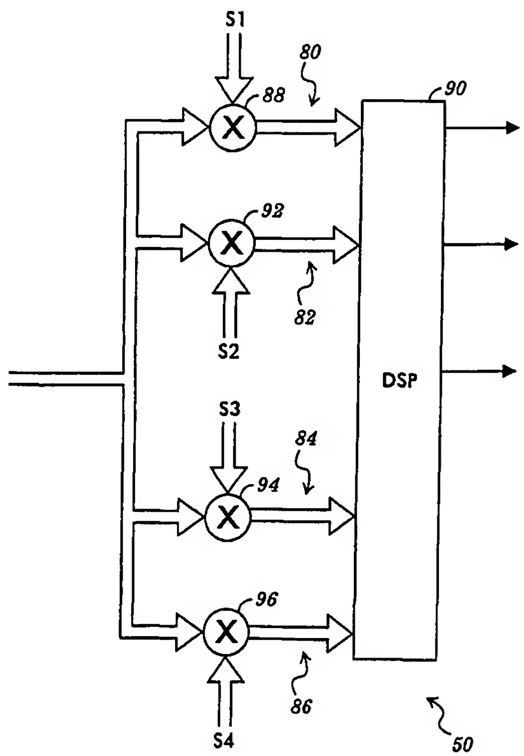

Figure 24